S
622.342
U39mdp
1977?
Read, Ransom F
Mineral
development
potential of the
Stillwater
Complex, Montana

Minerals Availability System

STATE DOCUMENTS COLLECTION

JAN 10 1990

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA, MONTANA 59620

A Decision Oriented Minerals Reserve/Resource Classification System

SUMMARY REPORT

MINERAL DEVELOPMENT POTENTIAL OF THE
STILLWATER COMPLEX, MONTANA

by

Ransom F. Read

PLEASE RETUR.

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR

MONTANA STATE LIBRARY
S 622.342 U39mdp 1977? c.1 Read
Mineral development potential of the Sti
3 0864 00065535 0

STATE DOCUMENTS COLLECTION

JAN 10 1990

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA, MONTANA 59620

SUMMARY REPORT

MINERAL DEVELOPMENT POTENTIAL OF THE STILLWATER COMPLEX, MONTANA

by

Ransom F. Read

NOTICE

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or the U.S. Government. The purpose of this report is to provide information for further review within the Bureau of Mines and by specialists in relevant disciplines in other organizations.

PLEASE RETURN

CONTENTS

	Page
Introduction	3
Location and access	3
Ownership and land situation	3
History	4
Regulation and taxation	4
Montana mining regulations	4
U.S. Forest Service mining regulations	6
Montana mineral industry taxation	6
Gross proceeds tax	6
Resource indemnity trust tax	6
Corporation license tax	7
Metalliferous mines license and taxes	7
Environmental considerations	7
Economic geology	8
General geology - Stillwater Complex	8
Description of deposits	8
Chromite	8
Platinum-palladium	9
Copper-nickel	10
Reserves/resources	11
Chromite	11
Platinum-palladium	11
Copper-nickel	11
Extraction methods	11
Mining	11
Beneficiation	12
Economic considerations	12
Chromite	12
Platinum-palladium	13
Copper-nickel	13
Conclusions	14
Bibliography	15

ILLUSTRATIONS

Fig.		
1.	Location and access map of Stillwater Complex	3
2.	Major claim map, Stillwater Complex	3
3.	General geology of the Stillwater Complex	8

TABLES

1.	Development and production history of Stillwater Complex chromite mines	5
2.	Characteristic chromite analysis - Mouat mine	9
3.	Characteristic metal values - Mouat copper-nickel sulfides	10

Digitized by the Internet Archive
in 2016

https://archive.org/details/mineraldevelopme1977read

INTRODUCTION

This report summarizes the geologic, mining, metallurgical, environmental, and economic factors influential to the short-term development potential of Stillwater Complex mineral resources. Commodities most likely to be mined are chromite, platinum-palladium, and copper-nickel ores. Economic development of the mineral deposits is contingent upon external supply conditions. Technology is available for the processing and utilization of the ores, but not currently at competitive costs. Aluminum and iron resources are not considered to be economically viable in the foreseeable future.

Location and Access

The Stillwater mining district is in Stillwater, Sweetgrass, and Park Counties, south-central Montana, and geologically within the Stillwater Complex. Principal routes into the Stillwater Complex are paved county roads leading up the Stillwater and Boulder River valleys from Columbus and Big Timber, Montana (fig. 1). These towns are served by Interstate 90 and the Burlington Northern Railroad and are the principal supply and shipping points for the region. Well-graded mountain roads provide local access to the Mouat and Benbow chromite mines, sites of previous large-scale mining activity. Other prospects are accessible by Forest Service and unimproved exploration-development roads. Vehicular travel is restricted by the few roads in the area, and access to higher elevations during winter months is impeded by heavy snow accumulation.

Ownership and Land Situation

The principal mineral land holdings are controlled by four major mining companies (fig. 2): (1) The Anaconda Company - copper-nickel and chromite; (2) AMAX - copper-nickel; (3) Cyprus Mines - copper-nickel; and (4) Johns-Manville Corporation - platinum-palladium. Lesser holdings are controlled by individuals and at least one small company. All commingled private lands and unpatented claims are encompassed by the Custer and Gallatin National Forests.

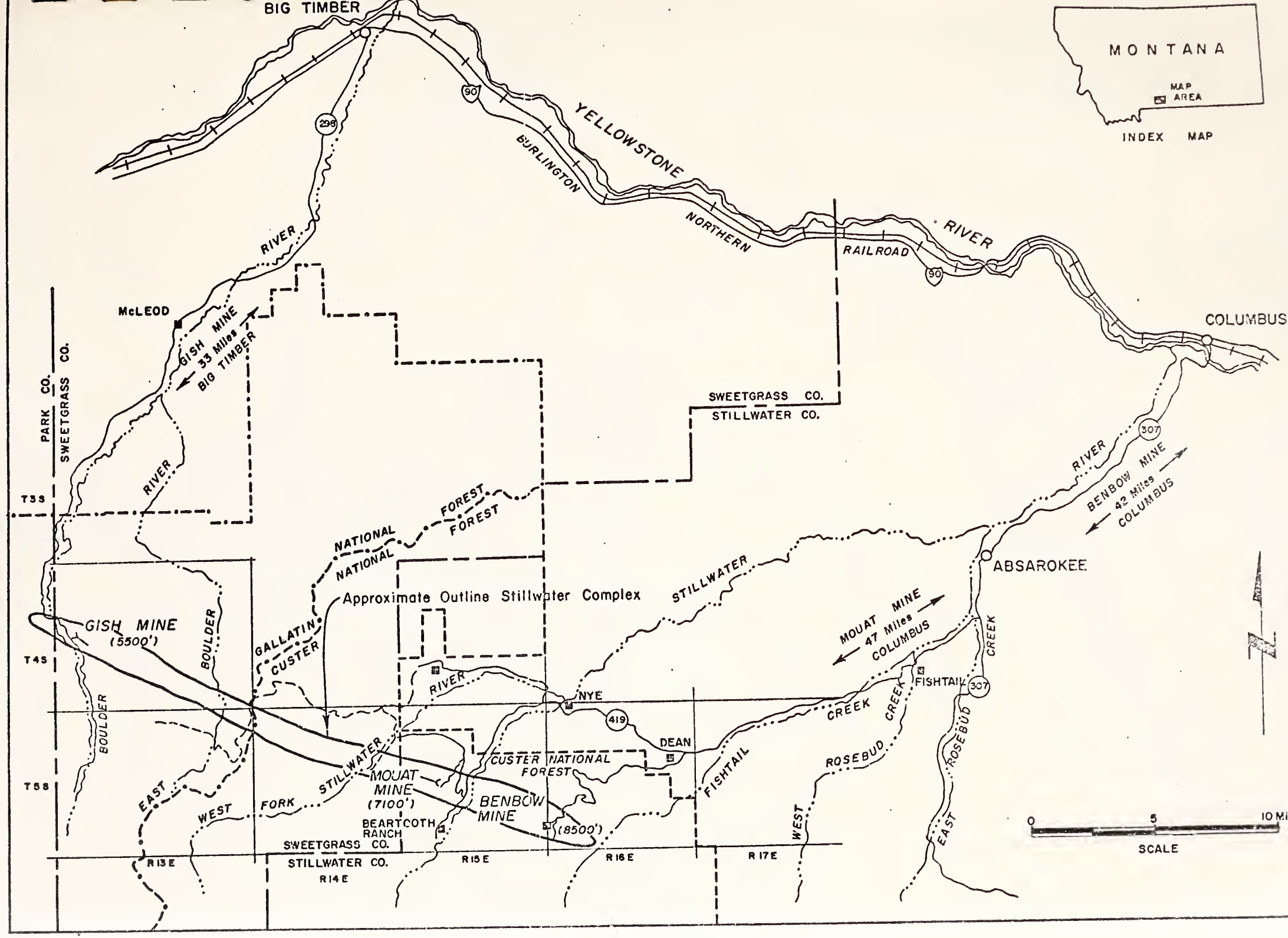

FIGURE 1. — Location and access map of Stillwater Complex

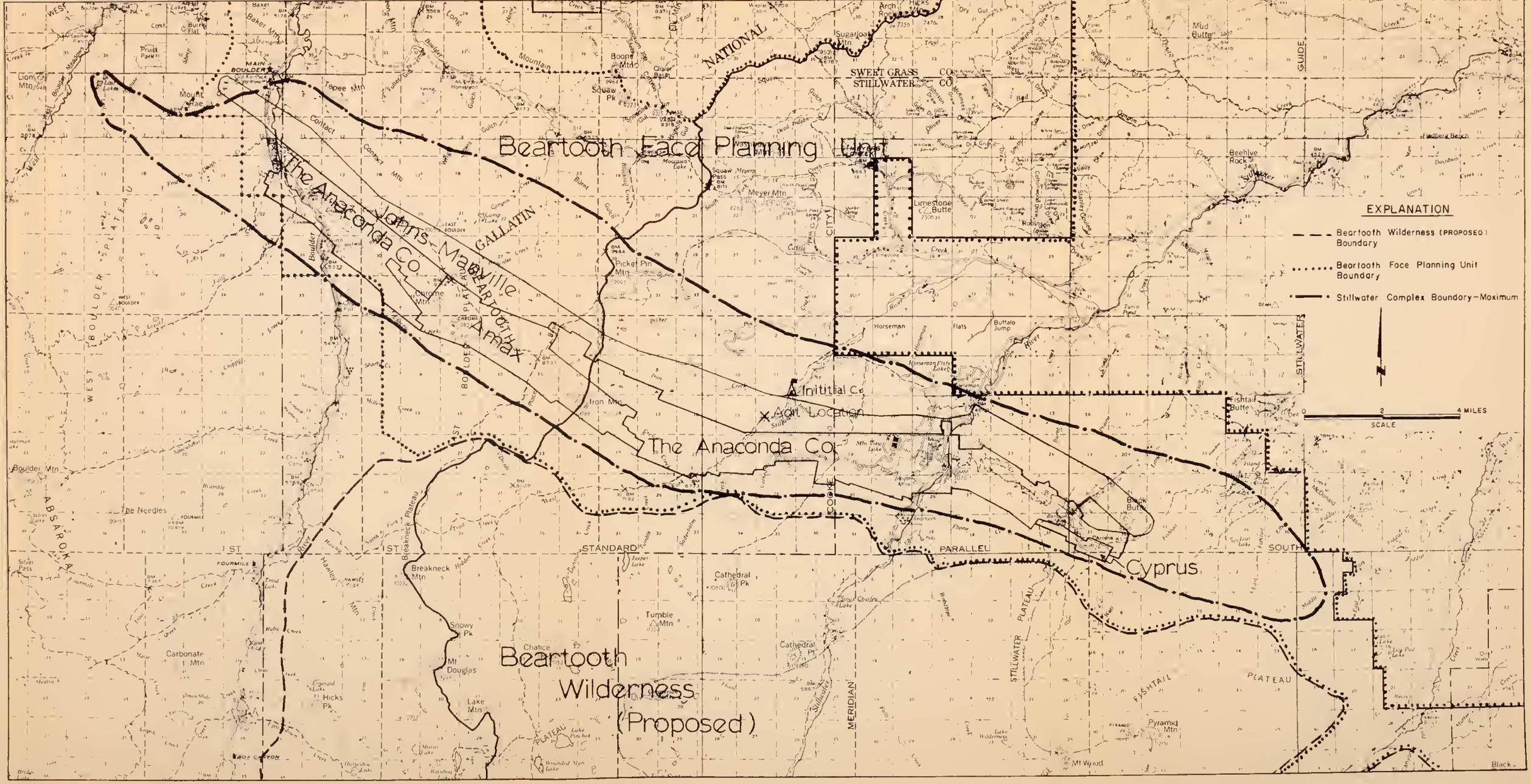

FIGURE 2 — MAJOR CLAIM MAP STILLWATER COMPLEX

History

The first patented mining claims in the Stillwater Complex were recorded in 1886. Since then, low ore grades and remoteness from markets precluded economic competition of the mineral deposits. Significant production from the Mouat and Benbow chromite mines resulted from the strategic importance of chromite in wartime emergencies. The outbreak of World War II and subsequent chromite supply interruptions led to intensive exploration and development of the deposits by the U.S. Bureau of Mines and the U.S. Geological Survey. Government subsidized contracts were let to The Anaconda Mining Company in 1941 and to the American Chrome Company in 1953 for development of the deposits and creation of a chromite stockpile as a hedge against national emergency. American Chrome, the larger producer, effectively reduced costs during fulfillment of its contract but had to discontinue operations because the Cr:Fe ratio could not be improved to meet industry requirements. The 950,000-ton (861,825.5-mt) GSA stockpile was sold to Metallurg, Inc., in 1974. The development and production history of the chromite deposits is summarized in table 1.

Since the late 1960's, the major mineral-related activities have involved exploration for copper-nickel sulfide ores and platinum group minerals. Johns-Manville Corporation, the most active company, drove an exploration-development adit on its platinum prospect on the West Fork of the Stillwater River in 1975-76. Surface drilling is continuing. AMAX has been exploring the Iron Mountain-Chrome Mountain area for copper-nickel since 1967. The Anaconda Company has continued to do assessment work on its claims, which include copper-nickel and chromite resource areas.

REGULATION AND TAXATION

Montana Mining Regulations

Montana state legislation governing the mining industry is primarily within the jurisdiction of the Department of State Lands and the Department of Health and Environmental Sciences. The Department of State Lands administers the New Hard Rock Law which provides for protection and reclamation of all affected lands within the state, from the mineral exploration stage through mining completion. License or permit approval for each operation-phase is contingent upon submission of an adequate reclamation plan and continued compliance with the statute. The Air and Water Quality Bureaus of the Department of Health and Environmental Sciences administer and enforce pollution control standards. Water rights, if needed, are obtained through the Department of Natural Resources and Conservation. The Safety and Health Bureau of the Department of Labor and Industry is responsible to enforce compliance with state mine safety regulations.

TABLE 1. - Development and production history of Stillwater Complex chromite mines[1]

Date	Benbow Mine	Mouat Mine	Gish Mine
1880-1918	Claims located Small-scale development No production	Same	Same
1918-1929	Developed by Chromium Products Corporation No production	--	--
1939-1945	Investigated by USBM and USGS to determine quantity, grade, extraction methods and beneficiation	Same	Same
1941-1943	Operator: Anaconda Company (government contract) Production: Mined-224,700 tons at 18.4 percent Cr_2O_3 Milled-186,369 tons at 18.34 percent Cr_2O_3 Conc.-72,566 tons at 41.46 percent Cr_2O_3 Underground devel. 46,787 ft.	Operator: Anaconda Company (government contract) Production: Mined-183,200 tons at 21.64 percent Cr_2O_3 Milled-77,696 tons at 19.26 percent Cr_2O_3 Conc.-29,538 tons at 38.81 percent Cr_2O_3 Underground devel. 38,658 ft.	Operator (1942): Anaconda Company (government contract) Production: Mined-small amount Milled-none Underground devel. 4,065 ft.
1948-1951	USBM conducted experimental mining and rehabilitation of the underground workings. Mined-8,646 tons at 20.41 percent Cr_2O_3	--	--
1953-1961	--	Operator: American Chrome Company (government contract) Production: Conc.-950,000 tons at 38.57 percent Cr_2O_3 Underground devel. 60,308 feet	--

[1] All tonnage figures are in short tons.

U.S. Forest Service Mining Regulations

Regulations were promulgated in 1974 by the Secretary of Agriculture to safeguard the surface resources of National Forest lands open to mineral location and entry under the General Mining Laws. The regulations require the filing of a "notice of intention to operate" if the proposed prospecting or mining is expected to cause surface disturbance. If significant environmental disturbance is foreseen, a plan of operations must be submitted for approval by an authorized Forest Service officer. The plan must describe the magnitude, environmental impact, and the time period of the contemplated operations. Rehabilitation measures that will be taken after mining or prospecting is completed must also be detailed. A bond equal to the expected rehabilitation cost may be required upon filing the operating plan. All activity must be conducted so as to minimize environmental impact and be in compliance with Federal, State, and local environmental and pollution control standards.

Montana Mineral Industry Taxation[1]

Gross Proceeds Tax

House Bill No. 198, Chapter No. 498, Montana Session Laws 1977, approved April 26, 1977, and effective for mine production during calendar year 1976, deletes metal mines from net proceeds taxation and provides for the ad valorem taxation of gross proceeds at a percentage of merchantable value. Under this law, the annual gross proceeds of metal mines is assessed at 40.0 percent of full cash value and taxed at 7.5 percent of true and full value at the mill levy rate of the local taxing district. Upon approval of pending legislation, the ad valorem taxation of gross proceeds will be 3.0 percent of assessed value, which is 100 percent of annual gross proceeds. Metal mines that produce less than 20,000 tons (18.143.7 mt) of ore per taxable year are exempt from property taxation on one-half of the merchantable value of the mine's product.

Taxable value of all real property and improvements is 40.0 percent of full cash value. New industrial property is taxed at 7.0 percent true and full value and mine machinery, not included in industrial property, at 30.0 percent at the local mill levy rate. If the ground surface of a mine is used for some other purpose than mining, it is assessed at full value and is also taxable for the other purposes. Property taxes are collected for the state by the County Treasurer.

Resource Indemnity Trust Tax

This tax applies to the market value of any merchantable mineral extracted or produced from the surface or subsurface during the calendar year. The annual tax is $25, plus an additional 0.5 percent of the gross value of the extracted mineral in excess of $5,000.

---

[1] Information received from the Department of Revenue, State of Montana.

Corporation License Tax

This tax is levied against the net income of corporations doing business in Montana. The rate is 6.75 percent of the net income derived from Montana sources, with a minimum tax of $50.

Metalliferous Mines License and Taxes

This tax is based on the gross value of all merchantable metals, precious and semi-precious gems and stones extracted or produced in Montana. The annual fee is $1 plus the gross production levy. Tax rates are 0.15 percent on gross value of 0-$100,000; 0.575 percent on $100,001-$250,000; 0.86 percent on $250,001-$400,000; 1.15 percent on $400,001-$500,000; and 1.438 percent on $500,001 and over. The average price listed in Engineering and Mining Journal is used as a base.

ENVIRONMENTAL CONSIDERATIONS

Short- and long-term environmental impacts of chromite and platinum-palladium mining are expected to be minimal. The ore minerals will be extracted by selective underground methods which will result in little surface manifestation. Large-scale copper-nickel mining will involve underground bulk mining methods, probably block-caving, that will eventually cause surface subsidence. Small amounts of copper-nickel ore are amenable to shallow open pit mining in a few restricted areas. In most cases, access to underground mines will be gained through adits driven at low elevations to avoid adverse weather conditions at higher elevations and provide low-level ore haulage to the mill. Deep shafts will be necessary for ventilation and probably for some access. The copper-nickel ore may cause acid and iron pollution of mine water that will have to be treated if released into surface drainages. Water will be recycled wherever possible. Waste rock will be disposed of near the mine openings and will be of similar composition as nearby talus slopes. Water runoff from waste dumps will have to be monitored for leaching effects. Tailings are most economically disposed of in level, open areas near the mill site. A few natural basins suitable for tailings disposal, such as Placer Basin and Forge Creek, exist near potential mine sites, but tailings may have to be transported via slurry pipelines to open areas immediately north of the Stillwater Complex.

Mining industry utilization of common service corridors for water, electricity, slurry pipelines, and access will lessen the environmental impact of surface facilities. Such corridors are limited by the rugged terrain, but the shortest route is usually economically preferable. Possible mill locations are the old Mouat and Benbow mill sites and the East and West Forks of the Stillwater and Boulder Rivers. The establishment of a Stillwater area mining industry will result in significantly increased population and traffic in the Stillwater and Boulder River valleys.

ECONOMIC GEOLOGY

General Geology-Stillwater Complex

The Stillwater Complex is a group of layered igneous rocks exposed as a rough lens 28 miles (45.1 km) long by 1 to 5 miles (1.6 to 8.0 km) wide (fig. 3). It lies along the northern margin of the Beartooth Mountains. The complex intrudes older Precambrian rocks to the south and is unconformably overlain by Middle Cambrian sedimentary strata to the north. During formation of the Beartooth Mountains, the complex was turned on edge, thrust north along faults, and exposed by erosion. The ore minerals and enclosing rocks formed in horizontal layers as a cumulate or "magmatic sediment" during fractionation of a basaltic magma (Jackson, 1968). In general, the layered rocks strike between N 60° W and N 80° W and dip steeply north.

For classification purposes, the Stillwater Complex is divided into four stratigraphic zones: Upper, Banded, Ultramafic, and Basal zones (fig. 3). Mineralogy is made relatively simple by the rhythmic occurrence of primarily six minerals: olivine, two orthopyroxenes, augite, chromite, and calcic plagioclase (Dayton, 1971). Chromite, an accessory mineral, is concentrated in 13 alphabetized chromitite layers within the Ultramafic zone. Platinum-group minerals are present in all zones, but most importantly in a sulfide horizon within the Banded zone. Copper-nickel is concentrated in and adjacent to the Basal zone, and is present in trace amounts throughout the complex.

Description of Deposits

Chromite

Important minable chromite resources are contained in the "G" and "H" chromitite layers at the Mouat and Benbow mine sites in the eastern part of the complex. The layers have been developed for several thousands of feet along strike and through a vertical range of about 1,000 feet (304.8 m) on both properties. Between the Mouat and Benbow mines, the chromite is well-exposed on the surface through an elevation range of almost 2,000 feet (609.6 m). Major fault and topographic parameters delimit the ore bodies. Ore zone widths are between 4 and 9 feet (1.2 and 2.7 m). The ore bodies consist of steeply dipping, irregular, and overlapping layers and lenses that produce sinuous ore-wallrock boundaries. Typically, massive chromite adheres to sharp footwalls, while disseminated ore and bands of waste produce gradational hanging walls. Although the mode of occurrence and geology is in all places similar, local conditions impose different mining requirements.

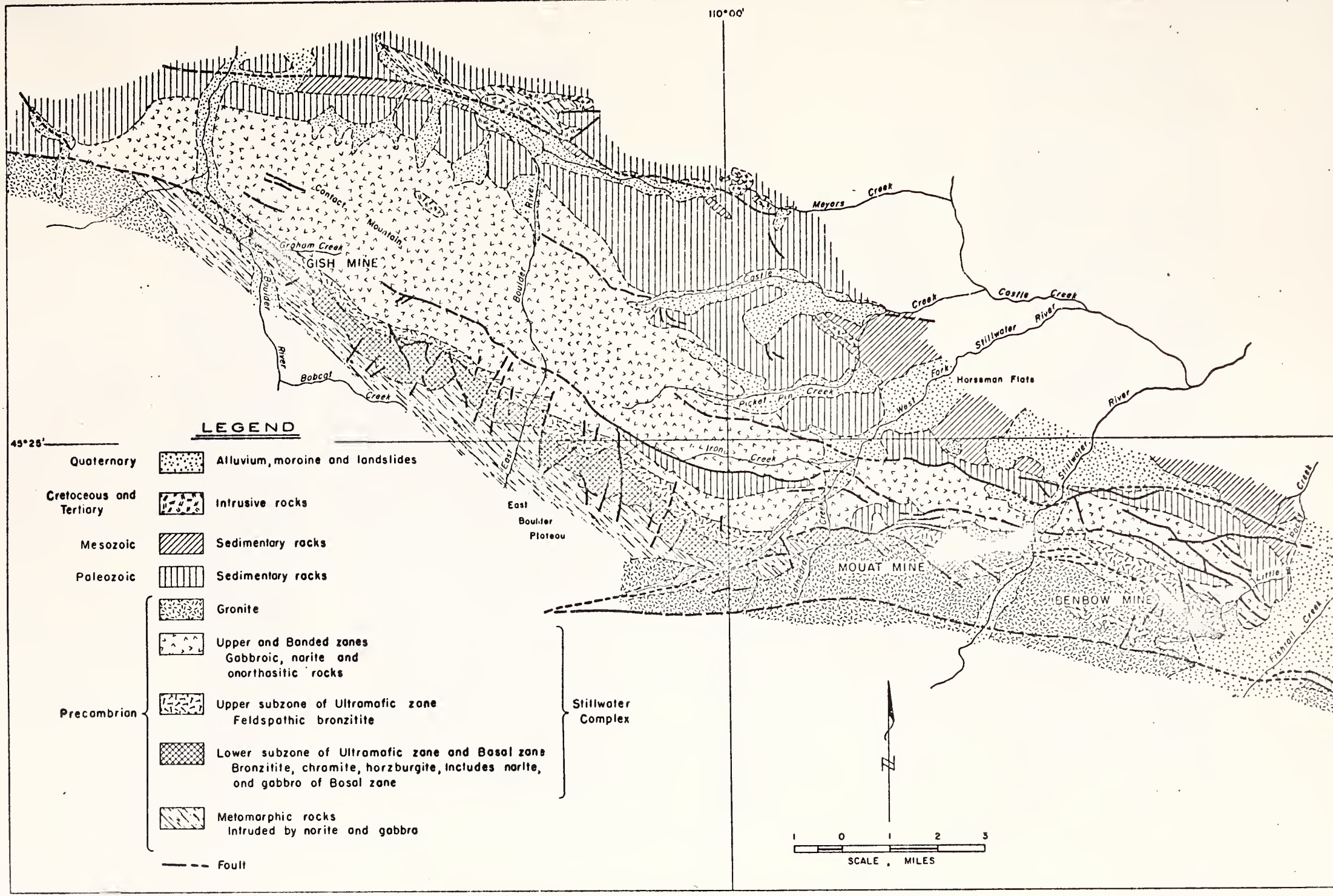

FIGURE 3.--General Geology of the Stillwater Complex

Modified from USGS Bull 1071-h

The ore mineral, chromite [(Mg, Fe) Cr, Fe, Al)$_2O_4$], is a complex solid-solution mineral composed of five major cations in varying proportions. Grade is dependent upon two factors: (1) proportion of chromite to gangue; and (2) the composition of the ore mineral itself. The Stillwater Complex chromite seldom contains more than 45 percent Cr_2O_3, with an average Cr:Fe ratio of 1.72:1. The "H" chromitite band is highest in grade and Cr:Fe ratio (Jackson, 1968). A typical mineral analysis is given in table 2. The chromite mineral grain size averages 1.5 mm. Olivine is the principal gangue constituent with pyroxenes and plagioclase usually comprising less than a few percent of a chromitite layer.

TABLE 2. - Characteristic chromite analysis - Mouat mine[1]

41.3 percent	Chromic oxide
17.6 percent	Iron
20.6 percent	Alumina
12.8 percent	Magnesia
0.7 percent	Silica
0.7 percent	Calcium oxide

[1] From: Mill Practice of American Chrome Company, presented at the Rocky Mountain Mineral Conference by William H. Hisbe (undated).

Platinum-Palladium

The platinum-palladium-bearing sulfide horizon being explored by Johns-Manville is within a lower anorthosite member of the Stillwater Complex' Banded zone. The sulfide horizon is narrow, having a minable width of about 7 feet (2.1 m). It has been followed intermittently some 20 miles (32.2 km) west from the original discovery point in the West Fork Stillwater River valley. An exploration adit from the West Fork valley has been driven at 6600 feet (2011.7 m) of elevation, over 2,000 feet (609.6 m) along the sulfide horizon. A number of diabase dikes and faults crosscutting the sulfide horizon have been exposed, and lateral displacement is on the order of 15 to 60 feet (4.6 to 18.3 m). There is approximately 2,750 feet (838.2 m) of relief from the adit to the horizon's surface outcrop between the West Fork Stillwater River and the East Boulder River.

The sulfide horizon contains 0.5 troy ounces per ton of platinum-group metals, approximately 0.05 percent copper, 0.10 percent nickel, and minor amounts of gold and silver. Sulfide minerals are principally pyrrhotite, pentlandite, and chalcopyrite, with the platinum metals associated with the pentlandite. The ratio of platinum to palladium is 1:3.5. The minerals have low sulfur content.

Fe_7S_8-FeS — dark grayish black streak

$(Fe, Ni)_9S_8$

$CuFeS_2$ — brass yellow

Copper-Nickel

Numerous irregular, lenticular and podiform copper-nickel sulfide bodies occur adjacent to and within the Basal zone of the Stillwater Complex. The enclosing rocks are Basal zone hornfels and norites and underlying Precambrian metasediments. Principal surface exposures are in the Benbow, Stillwater River, Placer Basin, and Boulder River areas. The copper-nickel zone is widest at the Mouat property near the Stillwater River.

The sulfide minerals are pyrrhotite, chalcopyrite, and pentlandite. The disseminated ore is valuable mainly for its nickel content with copper an important credit. Nickel is associated equally in the pentlandite and pyrrhotite. The chalcopyrite contains all the copper (telephone commun., Richard Siemens, Albany Metallurgy Research Center). Platinum-palladium values are variable, but the metals are recoverable. Two typical mineral examples from the Mouat area are given in table 3.

TABLE 3. - Characteristic metal values - Mouat copper-nickel sulfides[1]

0.46 percent	Nickel
0.40 percent	Copper
0.12 oz/ton	Silver
0.0020 oz/ton	Gold
0.0010 oz/ton	Platinum
0.0025 oz/ton	Palladium
0.55 percent	Nickel
0.40 percent	Copper
0.02 oz/ton	Silver
0.0080 oz/ton	Gold
0.0020 oz/ton	Platinum
0.0020 oz/ton	Palladium

[1] Letter: James E. Adler, May 5, 1975.

RESERVES/RESOURCES

Chromite

Demonstrated chromite resources of the Stillwater Complex are estimated at approximately 5 million metric tons of ore averaging 22.0 percent Cr_2O_3 by weight. The largest resource is at the Mouat mine, which is followed in total resource by the Benbow mine. The Gish mine, near the west end of the complex, has the smallest resource and the lowest Cr_2O_3 content (15.0 percent). Demonstrated reserves/resources will sustain a 500-mtpd mine and a 1,000-mtpd mine on the Benbow and Mouat sites for 10 and 20 years, respectively. Exploration drilling between the Mouat and Benbow mines, and deep-level drilling beneath the Benbow workings, could result in a substantial increase in potential reserves.

Platinum-Palladium

Platinum-palladium resources delineated by Johns-Manville in the Banded zone are expected to support a 2,000-mtpd mining operation for 15 to 20 years. Additional resources in the Ultramafic and Basal zones of the Stillwater Complex are large, possibly over 150 million troy ounces (4,665,629.9 kg) (Page and Dohrenwend, 1973).

Copper-Nickel

Published comprehensive resource estimates for copper-nickel are not available. However, a high copper-nickel resource is indicated for most of the Basal zone over its approximate 30-mile (48.3-km) strike length and in adjacent metasediments. Exploration by The Anaconda Company has resulted in resource estimates of 150 million tons (136,077,711.0 mt) of copper-nickel ore averaging 0.25 percent nickel and 0.25 percent copper content (Dayton, 1971). Total Stillwater Complex resources may be between 2 and 10 times as much according to Page and Dohrenwend (1973).

EXTRACTION METHODS

Mining

Both chromite and platinum-palladium ores will be removed by selective underground mining methods, dependent upon ground conditions and attitude and width of the ore zone. Narrow ore zones and sinuous ore-wallrock boundaries will make dilution control difficult and necessitate closely supervised drilling. Probable mine openings will be in the Stillwater and West Fork Stillwater River valleys. Inconspicuous high-level openings will be necessary for ventilation and personnel access and safety. Lead times necessary to reach full mine production levels of chromite and platinum-palladium are two to four years. Small amounts of chromite can be mined almost immediately from blocked-out and broken ore in the Mouat mine.

Copper-nickel ores are amenable to removal by surface and underground mining methods. Open pit mining will be limited to a few shallow deposits in restricted areas, which will be reclaimed and stabilized after mining. Major resources on both sides of the Stillwater River can be developed by deep-level adits driven into both walls of the Stillwater valley. The workings can also provide deep development openings to the major chromite resource areas. Coordination of contemporaneous or consecutive mining activity is economically and environmentally desirable.

Beneficiation

Flotation methods will be used to concentrate the platinum-palladium and copper-nickel ores. Gravity techniques will be used on the chromite ore, with supplementary treatment by flotation and/or high-tension electrostatic methods. Mills will be located as close as possible to the mine sites. A number of alternative tailings disposal sites exist and selection is dependent upon detailed studies. A preferred site for platinum-palladium tails is the Picket Pin ranch north of the West Fork Stillwater River. There will be no point source water discharge from the tailing ponds. All excess water and contained flotation reagents will be returned to the mill circuit.

All concentrate produced will require further metallurgical processing, preferably at the mill site. Feasibility studies are not complete to determine the extent of further on-site metal reduction. Shipment of mill concentrates to distant smelters and refineries will involve significant transportation costs.

ECONOMIC CONSIDERATIONS

The categorization of Stillwater Complex mineral commodities as "resources" indicates their subeconomic nature. Despite extensive knowledge of geologic, mining and metallurgical characteristics, remoteness from markets, ore quality problems, and anticipated large energy requirements for ore processing, continue to delay economic development of the mineral deposits.

Chromite

The Stillwater Complex is estimated to contain 70 percent of the domestic chromite resource--all of it a high-iron variety chromite, only marginally suitable for ferrochrome production. Ferrochromium is most important as an alloy in stainless steel production, for which it has no adequate substitute. Technologic progress in chromium ferroalloying is facilitating the utilization of high-carbon chromium, from high-iron chromite ores/concentrates, in the manufacture of stainless steel (Morning, 1977). These developments may enhance the suitability of the Stillwater chromite ore. Stillwater concentrates have been more suitable as chromite source materials for use in the chemical and refractory industries.

U.S. demand for primary chromium in 1975 was 372,000 tons (337,472.7 mt); in 1985 and 2000 the forecasted annual demand is 670,000 tons (601,813.8 mt), and between 840,000 tons and 1,280,000 tons (762,035.2 and 1,161,196.5 mt), respectively (Morning, 1977). Identified Stillwater resources are on the order of 6.5 million metric tons containing approximately 1.4 million metric tons Cr_2O_3.

Platinum-Palladium

As in the case of chromium, the U.S. is dependent upon foreign suppliers for nearly 100 percent of its annual primary platinum-palladium requirements. Consumption in 1974 was 848,000 troy ounces (26,376.4 kg) platinum and 673,000 troy ounces (20,993.1 kg) palladium. Demand in 1985 is forecast to be 805,000 troy ounces (25,038.9 kg) and 100,000 troy ounces (27,993.8 kg), respectively (Butterman, 1975). Development and production from platinum-group metal deposits in the Stillwater Complex Banded zone would reduce import dependency by less than 10 percent platinum and 20 percent palladium of the 1985 forecasted demand. Simultaneous production of platinum-palladium from copper-nickel deposits would further offset demand. Present prices for platinum-palladium are considered too low for economic development of the deposits.

Copper-Nickel

The Stillwater Complex copper-nickel deposits are important for their nickel values. Copper is more readily available from other large, higher-grade mineral deposits. Current U.S. nickel production is from one nickel laterite mine in Oregon. Production from the mine satisfied about 7 percent of total U.S. demand for primary nickel in 1973-74. Primary consumption of nickel in 1974 was 193,600 tons (175,631.0 mt); anticipated demand in 1985 and 2000 is expected to be 260,000 tons (235,868.0 mt) and 385,000 tons (349,266.1 mt), respectively (Corrick, 1975). Technology is well developed for the mining and beneficiating of nickel sulfide ores, and development of the Stillwater deposits is contingent upon the market price.

CONCLUSIONS

The Stillwater Complex contains chromite, platinum-palladium, and copper-nickel ores that can be used in industry should they become economically viable or should strategic reasons necessitate their extraction. Any mining of these commodities can only partially offset domestic demand. Chromite is the most essential strategically because of its importance as an alloying agent and our heavy reliance on distant suppliers. Increased suitability of the chromite concentrate through ferroalloying innovations coupled with higher import prices may result in eventual economic production from the deposits. Development of platinum-palladium and copper-nickel resources is largely dependent upon market conditions. Canada, a large exporter of these commodities to the U.S., exercises significant price control. If present market conditions prevail and no disruption of crucial commodity supply occurs, development of the Stillwater mineral resources is not imminent.

BIBLIOGRAPHY

Anonymous. Chromium Materials Survey. U.S. Dept. Commerce, 1962, 96 pp.

Butterman, W. C. Platinum-Group Metals in Mineral Facts and Problems. Bur.Mines Bull. 667, 1975, pp. 835-854.

Cornwall, H. R. Nickel Deposits of North America. U.S. Geol. Survey Bull. 1223, 1966, 62 pp.

Corrick, John D. Nickel in Mineral Facts and Problems. Bur.Mines Bull. 667, 1975, pp. 735-748.

Dayton, S. Profile of a Hearing on Mineral Entry (Hot Air Over Stillwater). Eng. and Min. J., v. 172, No. 10, 1971, pp. 75-84.

Hess, H. H. Stillwater Igneous Complex, Montana. Geol. Soc. Amer. Mem. 80, 1960, 230 pp.

Howland, A. L., E. M. Garrels, and W. R. Jones. Chromite Deposits of the Boulder River Area, Sweetgrass County, Montana. U.S. Geol. Survey Bull. 948-C, 1949, pp. 63-82.

Howland, A. L., J. W. Peoples, and E. Sampson. The Stillwater Igneous Complex and Associated Occurrences of Nickel and Platinum Group Metals. Mont. Bur.Mines and Geol. MC No. 7, 1936, 15 pp.

Jackson, E. D. The Chromite Deposits of the Stillwater Complex, Montana. In Ore Deposits in the U.S., 1933-1967, (Graton Sales), v. 2. New York, AIME, 1968, pp. 1495-1510.

Jones, W. R., J. W. Peoples, and A. L. Howland. Igneous and Tectonic Structure of the Stillwater Complex, Montana. U.S. Geol. Survey Bull. 1071-H, 1960, pp. 281-340.

Morning, J. L. Chromium--1977, Mineral Commodity Profiles. Bur.Mines May 1977, 14 pp.

Page, N. J., and J. C. Dohrenwend. Mineral Resource Potential of the Stillwater Complex and Adjacent Rocks in the Northern Part of the Mt. Wood and Mt. Douglas Quadrangles, Southwestern Montana. U.S. Geol. Survey Circ. 684, 1973, 9 pp.

Peoples, J. W., and A. L. Howland. Chromite Deposits of the Eastern Part of the Stillwater Complex, Stillwater County, Montana. U.S. Geol. Survey Bull. 922-N, 1940, pp. 371-416.

Price, P. M. Mining Methods and Costs, Mouat Mine, American Chrome Company, Stillwater County, Montana. Bur.Mines Inf. Circ. 8204, 1963, 58 pp.

BIBLIOGRAPHY--Continued

Roby, R. N. Investigation of Copper-Nickel Deposits of the Stillwater Complex, Stillwater and Sweetgrass Counties, Montana. Bur.Mines Rept. Invest. 4431, 1949, 10 pp.

Wimmler, N. L. Investigation of Chromite Deposits of the Stillwater Complex, Stillwater and Sweetgrass Counties, Montana. Bur.Mines Rept. Invest. 4368, 1948, 41 pp.